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ROTS OF EARLY STRAWBERRIES IN FLORIDA AND SOUTHERN CALIFORNIA

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The fungi causing rots of strawberries in the southern states have been under investigation since 1915. Each season Florida strawberries have been examined either in the field or in the market by one or more of those interested in the investigation. During several seasons shipping tests were carried on, and the same fruit was examined both before and after shipment. Although there have been found on Florida strawberries fungi belonging to numerous genera, *Rhizopus nigricans* Ehrb. has remained the commonest and most destructive of the fungi causing decay of ripe strawberries from this region.

Four months' study, January to May 15, 1920, of southern California strawberries both in the field and in the market showed a condition quite different from that in Florida. *R. nigricans* appeared to be of distinctly minor importance as a cause of fruit rot of strawberries; whereas a large proportion, frequently over ninety percent, of the rotten berries examined during the four months were affected with a species of Botrytis, probably *Botrytis cinerea* Pers.

There is, then, apparently a marked difference in the relative abundance of these fungi on early strawberries in the two regions, and the probable reasons for this difference are discussed in the present paper. No one would, of course, presume to generalize from the observations of a single season, but so competent and experienced an observer as Dr. H. S. Fawcett of the Citrus Experiment Station at Riverside, California, assures the writer that the extreme prevalence of Botrytis on strawberries is a regular phenomenon of the winter season in southern California.

The regions under consideration include the most southerly important strawberry shipping points on the Atlantic and Pacific seaboards. The strawberry-growing region of central Florida lies east of Tampa, Plant City and Lakeland being the chief shipping points. The southern California strawberry area lies chiefly in Los Angeles county, Gardena and Moneta being large shipping points. Attention will be confined to the early shipping season, during a portion of which these two regions usually dominate their respective markets.

THE FUNGI

In using the specific names *Rhizopus nigricans* and *Botrytis cinerea*, the writer does not intend to enter upon the debated ground as to whether the fungi so designated constitute good species or collections of species. It is intended merely to indicate that the material studied accords morphologically with the species that have been more or less generally known by those names and produces the characteristic effect on strawberries. It is probable that more than one variety, or species, of each genus occurs on strawberries, and both genera are now being studied by competent investigators, to whom material from strawberries has been supplied.

Both species are widely distributed on a variety of hosts, and there can be no question but that they have long been present in both the areas discussed. The striking difference in their abundance in the two areas must then be due to environmental conditions and not to lack of opportunity for infection. Additional indication that the extreme prevalence of Botrytis in California is due to environmental conditions is found in the fact that Fawcett (7, pp. 207, 209), who has carefully studied Citrus diseases in both Florida and California, finds a similar condition. He reports Botrytis as causing gummosis of trunk and limbs, and a fruit rot of lemons in parts of California, but not in Florida or Cuba.

Host Relations

Commercial strawberry picking in southern California usually begins in March (6, p. 22), although some ripe strawberries may often be obtained throughout the winter, and in very favorable seasons commercial shipments have been made every month in the year. The bulk of the long-distance shipments, however, are made in the month or six weeks following the first general ripening, that is, before the crop ripens in the important strawberry-growing regions of central California. Commercial picking in central Florida usually begins in January, sometimes even before Christmas, and, except when interrupted by frost, long-distance shipments are continued until strawberries ripen abundantly in northern Florida, which is usually in March (5, p. 4). The first four months of the year include, then, the time of earliest picking and the period of important commercial long-distance shipments in both districts.

The standard commercial variety of strawberries in central Florida is the Missionary, in southern California the Brandywine. There is no evidence, however, that the difference in the varieties grown in the two localities influences the relative abundance of the two fungi. Indeed, it has thus far been impossible to demonstrate any varietal resistance to either of these fungi.

With the possible exception of irrigation, which is discussed later, the difference in cultural practice (5, 6) seems to bear no relation to fungous infection.

Climatic Relations

The most striking differences between the areas under discussion are climatic. The climatic differences seem, moreover, to bear a close relation to the difference in the prevalence of the two fungi. Though the writer is responsible for the views on the relation of weather conditions to fungous growth here presented, he has received much assistance in the compilation and interpretation of weather data from the meteorologists in charge of the U. S. Weather Bureau stations nearest the regions discussed, W. J. Bennett of Tampa and H. B. Hersey of Los Angeles.

In comparing the climatic conditions of the strawberry-growing regions of central Florida and southern California, it is necessary to make use, in part, of the meteorological data from Tampa and Los Angeles. These data are, of course, not entirely representative of conditions in the strawberry fields, since the stations are located in cities. The two stations are, however, about equally distant from the strawberry-growing areas, and bear somewhat the same relation to them. Moreover, good thermograph records are available from field stations at relatively short distances from the strawberry regions, and these have been used in comparing temperature conditions. At least the weather data here used represent conditions in the strawberry fields with a degree of accuracy well within the limit of error of such field observations as are here recorded.

MOISTURE CONDITIONS

The prevalence of Botrytis on strawberry fruits in semi-arid southern California was surprising in view of the fact that in the southeastern states it has been repeatedly observed (10, p. 8) that abundance of Botrytis on strawberries was closely associated with excessive precipitation. The mean annual precipitation at Tampa (49.40 inches) is much greater than that of Los Angeles (15.62 inches). The period under discussion, however (January to April), comes within the "dry season" in Florida and the "rainy season" in California. As shown by the Annual Meteorological Summaries for 1920 published by the two stations (table 1), the mean precipitation for this period as well as for the month of December is actually greater at Los Angeles than at Tampa.

TABLE 1. *Monthly Mean Precipitation, in Inches*

	Los Angeles, Cal., 1877–1920	Tampa, Fla., 1890–1920
December	2.67	2.05
January	3.34	2.62
February	3.19	2.75
March	2.92	2.20
April	0.89	1.92

Surface irrigation of strawberries is very rare in Florida but is regularly practised in California, a fact which still further increases the amount of water actually used on strawberry beds in the latter state while the berries are ripening.

Soils vary greatly in both regions, but in general the strawberry soils of central Florida are more sandy than those of southern California. The surface of a sandy soil of course dries quickly. Humidity conditions thus seem to be at least as favorable for the development of Botrytis during these months in southern California as in central Florida. If anything, they are somewhat more favorable. In fact, as Bennett has recently shown (2), the region about Tampa has, for so southern a station, a remarkably low relative humidity.

Temperature Relations

The difference in the temperature of the two regions presents a very interesting correlation with the difference in the temperature relations of the fungi under consideration, and seems to account in large part for the difference in the relative abundance of these fungi on strawberry fruits.

The exact determination of the minimum and optimum temperatures for the growth of an organism is very difficult. Both minimum and optimum temperatures of fungi have been shown to vary with the substratum used and with the duration of the test. It is unlikely, also, that the behavior of a fungus under constant temperatures in the laboratory exactly corresponds to its behavior under changing climatic temperatures. However, its average temperature reactions under maintained conditions furnish our only available basis of comparison with the behavior of a fungus under natural conditions.

Earlier studies (9) of the writer agree with those of Ames (1) and Hanzawa (8), and with the recent results of Brooks and Cooley (4), in placing the minimum for active growth of *Rhizopus nigricans* at about 7.5° to 8° C. (45.5 to 46.4 F.) and the optimum between 30° and 35° C. (86° and 95° F.). In contrast (3), *Botrytis cinerea* will grow somewhat at 0° C. (32° F.) and freely at 2° C. (35.6° F.). Its growth is most abundant at about 25° C. (77° F.) and falls off rapidly at 30° C. (86° F.). Whether these temperatures represent absolute minima and optima for the growth of the two fungi is of little present interest. They may fairly be taken to indicate that the temperatures favorable for the growth of *Rhizopus nigricans* are markedly higher than those for *Botrytis cinerea.*

As yet no thoroughly satisfactory way of expressing the value for plant growth of any given series of climatic temperatures has been devised. Where thermograph records are available, however, the monthly mean hourly temperatures certainly give some indication of the temperature conditions to which an organism is subjected in a given locality. Figures 1 to 4 show the mean hourly temperatures for the first four months of the year at two stations in southern California and two in central Florida.

The curve for Tampa is based on mean temperatures for the years 1910 to 1919 computed by W. J. Bennett, and that for Los Angeles on mean temperatures for the years 1919 and 1920 furnished by H. B. Hersey. The curves for Brooksville, Florida, and Pomona, California, are based on data

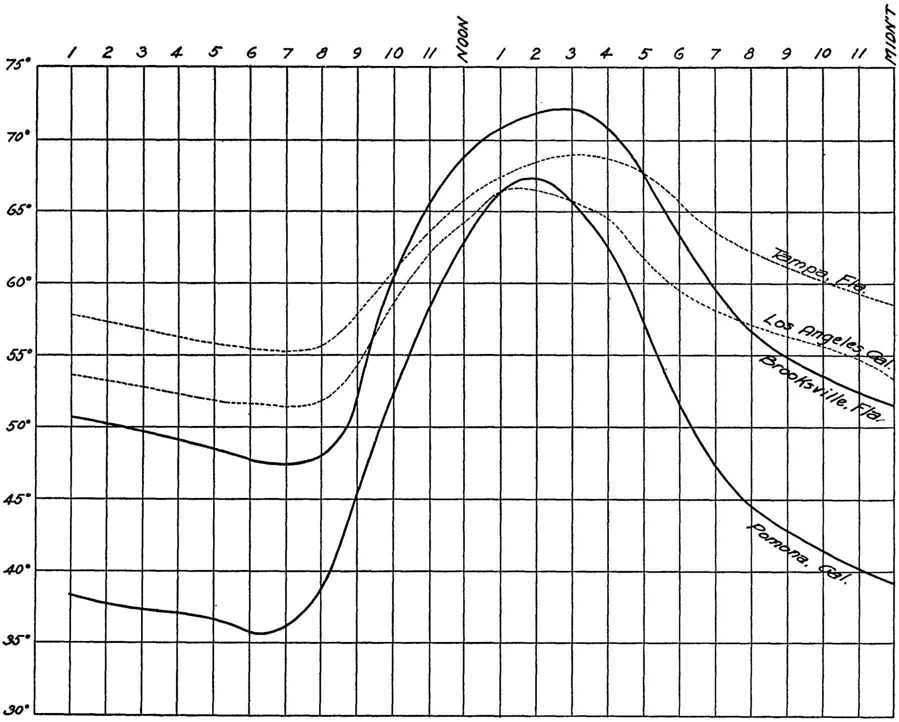

FIG. 1. Mean hourly temperatures for January at Pomona, California (field station), 1919 and 1920; Brooksville, Florida (field station), 1919 and 1921; Los Angeles, California (city station), 1919 and 1920; and Tampa, Florida (city station), 1910 and 1919.

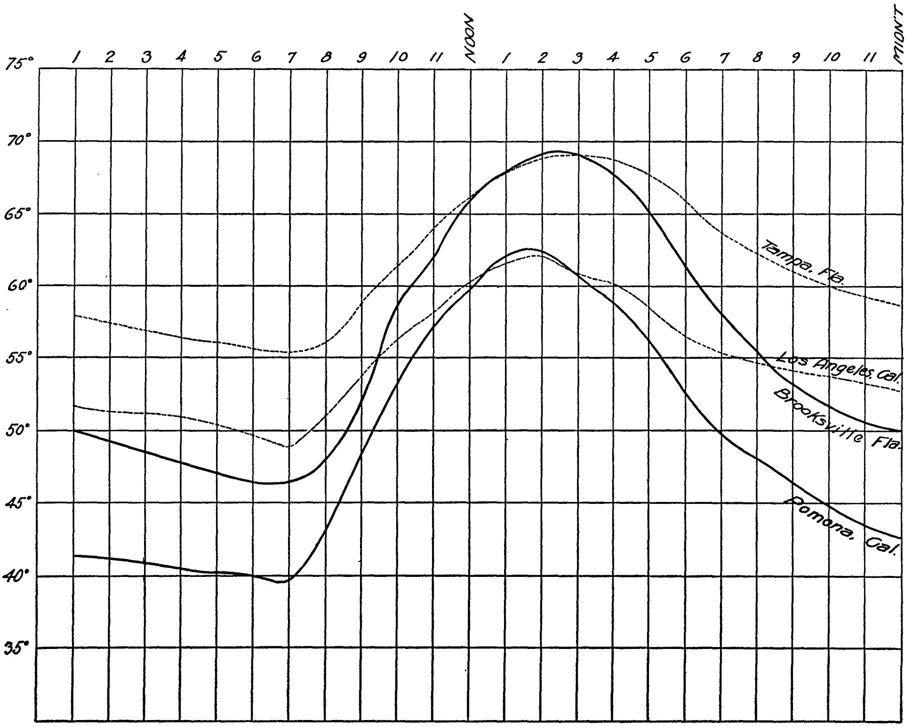

FIG. 2. Mean hourly temperatures for February at stations listed under figure 1.

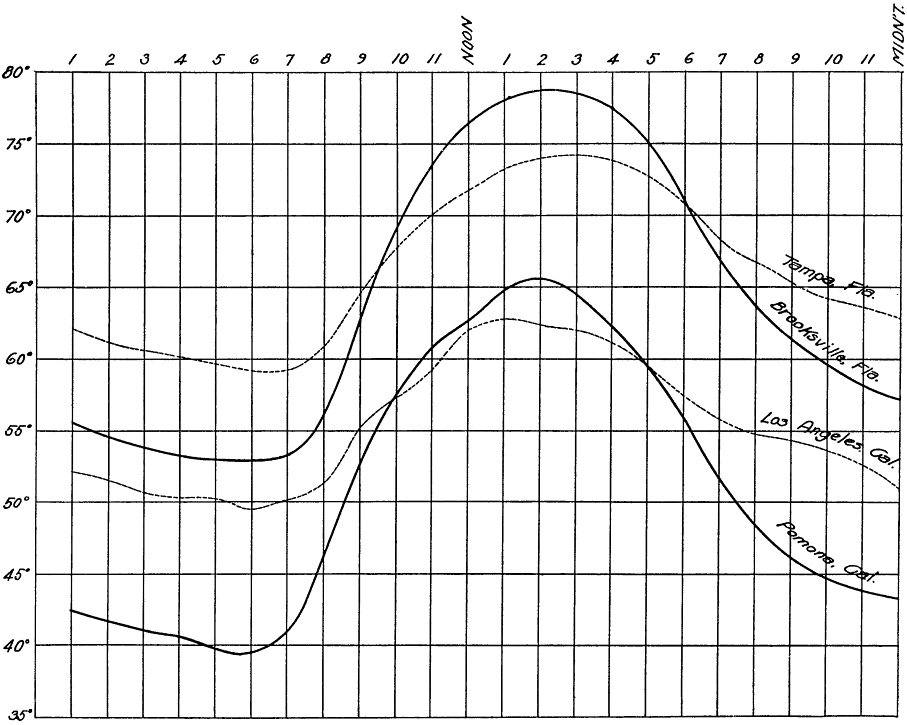

FIG. 3. Mean hourly temperatures for March at stations listed under figure 1.

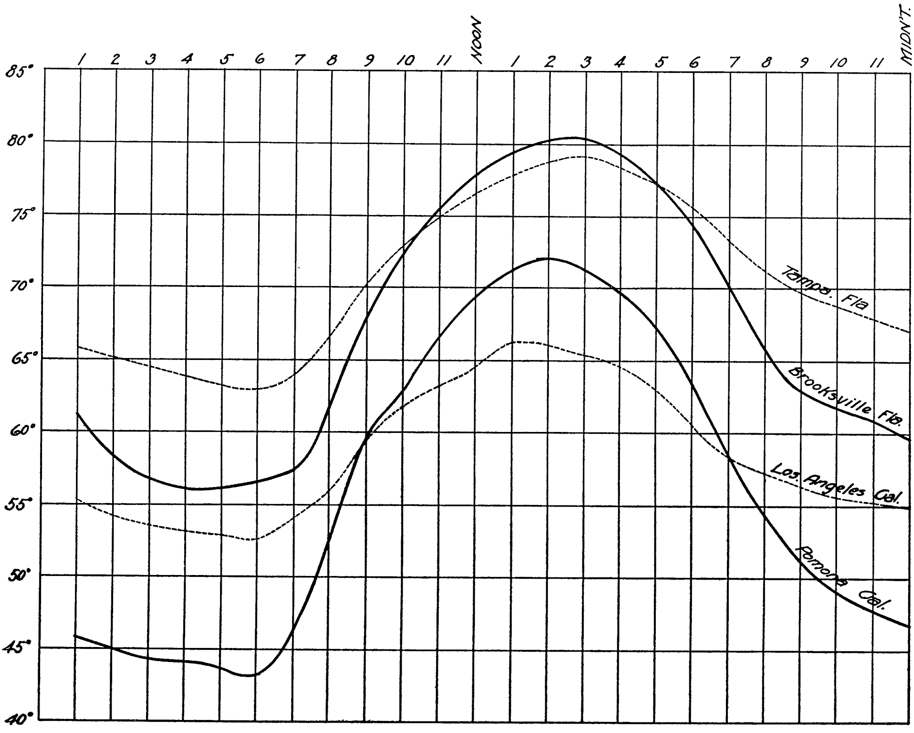

FIG. 4. Mean hourly temperatures for April at stations listed under figure 1.

from original thermograph records corrected by daily maximum and minimum thermometer readings for two seasons (Brooksville, 1919 and 1921; Pomona, 1919 and 1920). While the curves are not strictly comparable, they nevertheless furnish a fairly reliable basis of comparison, since including data for a longer period at the three latter stations would alter the shape of the curves but little. The data for the field stations, Pomona and Brooksville, of course approximate the conditions under which strawberry plants grow more closely than those for the city stations.

The range of mean hourly temperatures in the field in central Florida, January to April, as shown by the curves for Brooksville, is from about 47° F. to 80° F., temperatures known to be favorable for the growth of *Rhizopus nigricans.* In the region about Pomona, California, on the other hand, there is a period each day during which the temperature is less than 47° F., the minimum temperature at which *R. nigricans* grows under most conditions. In January there are about twelve hours out of the twenty-four during which the temperature is below 45° F., in February there are nearly ten, in March nine, and even in April there are five hours each day below this temperature. During this period, more than one third of the day, even in March, *Rhizopus nigricans* is able to make little if any growth. The mean temperature, however, does not go below 35° F., at which temperature *Botrytis cinerea* grows readily. There is thus throughout the winter a daily period, averaging one half the day in January, during which *B. cinerea* grows without competition from Rhizopus.

The writer believes that in this fact is found one of the chief causes of the great prevalence of Botrytis on strawberries and perhaps on other hosts in California during the winter. Under the temperature conditions which prevail in Florida, the rapid growth and abundant spore production of *R. nigricans* enable it to compete successfully with the numerous fungi which are known to infect strawberry fruits. Indeed, it may well be that the temperature of strawberries in Florida is frequently so high as to hinder the growth of Botrytis. Previous studies (11, p. 179) have shown that the temperature of strawberry fruits in the sun is often ten or more degrees C. above that of the air. Under mean shade temperatures of 72° to 80° F., strawberries in the sun may be expected to reach temperatures of 90° to 100° F., which are well above those most favorable for the growth of Botrytis. This may indeed be an important factor, hitherto overlooked, in the favorable influence of rainy weather on the growth of Botrytis. For not only are rainy days generally cooler than clear ones, but on such days the berries remain at or near the temperature of the air, and thus at temperatures more favorable for the growth of Botrytis than the much higher temperatures reached on clear days.

In California, on the other hand, the ability of *Botrytis cinerea* to grow at the lower temperatures gives it an enormous advantage over *Rhizopus nigricans* and over fungi with similar temperature requirements. In the relation of these two fungi on early strawberries, conditions are much like those in refrigerator cars (10, p. 10). That is, temperatures are common under which *Botrytis cinerea* is able to develop readily while the growth of *Rhizopus nigricans* and of fungi with similar temperature requirements is largely inhibited. This partial freedom from competition enables *Botrytis cinerea* to occupy in California a much more important place as a fruit rot of strawberries than in the southeastern United States.

SUMMARY

Rhizopus nigricans, known to be the most common cause of decay of ripe strawberry fruits in Florida, is of minor importance on winter strawberries in California.

Botrytis cinerea, which is common on strawberries only under conditions of extreme moisture in Florida, is regularly abundant in California during the winter.

This difference seems to be due in part to the somewhat more favorable moisture conditions in California, but especially to the fact that during the winter months there is a daily period during which the temperature is favorable for the growth of *Botrytis cinerea*, but unfavorable for the growth of *Rhizopus nigricans*.

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